ULTRASONIC SENSORS FOR THE ELDERLY AND CAREGIVERS IN A NURSING HOME

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Abstract: Workloads on caregivers in nursing home are increasing as the imbalance between the number of elderly people and that of caregivers becomes larger. Excessive workloads on caregivers must be reduced not only because they become burdens for caregivers but also because they deteriorate the quality of nursing care. One of such workloads is routine patrol for monitoring the status of the elderly and for detecting accidents on the elderly as soon as possible. If the number of unnecessary patrols is minimized, caregivers will be able to spend their time on high touch care and humane communication. The authors have been developing an ultrasonic 3D tag system which locate ultrasonic tags in real time, and employed the system in a nursing home to monitor positions of the elderly people. If the system locates the elderly people continuously and robustly, and if it can notify caregivers about the occurrence of accident-prone activities promptly, caregivers will be releaved from their unnecessary workloads. This paper describes the research background, system overview, system implementations, and experimental results.

1 INTRODUCTION

The world has been rapidly aging during the last few decades and it is projected that this trend will continue for several more decades. Aging of population has become one of the most serious and urgent problems that almost all the countries are facing and must tackle. Problems incurred by aging are not only the problem of decreasing working populations but also the problem related to the shortage of caregivers for elderly people. The number of the elderly of whom each caregiver takes care in nursing homes is certainly increasing and the imbalance between the number of the elderly and that of caregivers will deteriorate the quality of nursing care.

In nursing home, caregivers patrol the entire home regularly to prevent the elderly from meeting with serious accidents and, even if they have accidents, to detect occurrence of accidents promptly. Besides such patrolling, caregivers must often visit nursing rooms where nurse calls sounded from to take care of inhabitants. The number of caregivers is usually much less than that of the elderly so they are very busy taking care of the elderly. There is an overwhelming need for alleviating such workloads on caregivers.

On the other hand, the authors are involved in research on “human behavior modeling”(Hori, 2001; Nishida et al., 2004) and have been developing an environment in which a system observes inhabitants and recognizes their behaviors(Kitamura et al., 2004). By installing such observation system into elderly care homes, we believe that the system can recognize the behaviors of elderly people and provide some *useful support* for caregivers. To be concrete, if the system can detect accident-prone activities of the elderly beforehand and notify caregivers of the occurrence, their excessive patrols for detecting accidents or accident-prone activities will be minimized and, consequently, caregivers will be able to spare their time for high tough care for and humane communication with the elderly.

This paper introduces an ultrasonic sensor system for a nursing home. The system uses ultrasonic sensors to observe activities of the elderly people in a nursing room. The system is composed of two subsystems, a *wheelchair locator subsystem* and an *ultrasonic radar subsystem*; the former works for tracking position of a wheelchair which an elderly person uses and the latter monitors human head’s position on and around bed. When these two subsystems work cooperatively, activities of the elderly in a nursing room are monitored continuously and remotely without invading his/her privacy, so their accidents will be avoided or minimized if the system can recognize and notify the accident-prone activities to caregivers beforehand.

This paper is organized as follows: Section 2 presents several works related to location systems and support technologies. Secondly, Section 3 describes background of the system and outline of the system, briefly. Then Section 4 presents the system implementations and several experimental results and, finally, Section 5 concludes this paper.

2 RELATED WORKS

Concerning location systems and their technologies, Hightower and Borriello presented a good survey and taxonomy in IEEE Computer(Hightower and Borriello, 2001).

The Active Bat system(Harter et al., 1999) developed at AT&T Cambridge is the system which is almost same to ours. The system uses ultrasonic emitters, Active Bats, and a grid of ceiling-mounted ultrasonic receivers. Bats are attached to objects or personnel and their positions are computed with the accuracy of approximately 3cm.

The Cricket Location Support System(Priyantha et al., 2000) takes the opposite approach. In this system, ultrasonic emitters are installed in the environment and receivers are embedded in the objects. So triangulation computation is performed on the objects' side and, therefore, privacy of humans who have objects is not invaded.

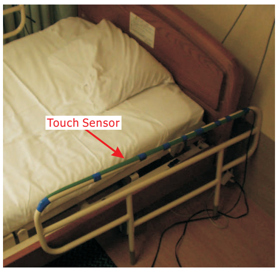
As for support technologies, many interesting articles are posted in IEEE Pervasive Computing.

Stanford introduced an elder care home, the Oatfield Estates(Stanford, 2002). The home had employed IR and RF wireless communication technologies not only for surveillance but also for monitoring health condition of the elderly.

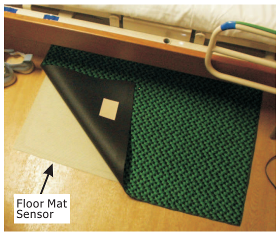
The CareMedia project is an on-going research project at CMU(Hauptmann et al., 2004). They installed four cameras and microphones in a nursing home in Pittsburgh and recorded video images over a week in their preliminary study. Analyzing the video, they tried to track the elderly's movement and to extract their activities in the nursing home.

SIMBAD (Smart Inactivity Monitor using Array-Based Detectors) is a sensor system developed by Sixsmith(Sixsmith and Johnson, 2004). They utilize IR sensor arrays as thermal imaging detectors to observe (in)activities of inhabitants.

Similar systems are too numerous to mention. We believe that this is because these support technologies are getting a lot of attention all over the world.



(a) Touch sensor on a handrail of a bed



(b) Floor mat sensor at bedside

Figure 1: Sensors used in a nursing home

3 ULTRASONIC SENSOR SYSTEM FOR ELDERLY CARE HOMES

This section firstly presents the background of this project. Then the Ultra Badge System developed by the authors is introduced briefly and, lastly, we outline our proposed system for elderly care homes.

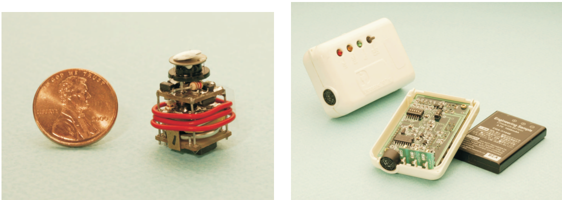
3.1 Background of the Project

The authors started the "Sensorized Elderly Care Home" project in the mid-summer of 2003 and have been implementing a system which reduces workloads on caregivers using a sensor network. This is a cooperative project with a nursing home in Tokyo.

To begin with, we interviewed caregivers of the nursing home and categorized accidents of the elderly into the following two cases:

1. **Falls**—Users of wheelchair or walker tend to fall down when they transfer from their wheelchair/ walker to their bed or a toilet seat and vice versa.
2. **Wanders**—Elderly people who suffer from senile dementia, such as Alzheimer's disease, tend to wander around day and night.

To detect these accidents, several kinds of contact-type sensors are already used in the nursing home. For example, touch sensors (Figure 1(a)) were attached to handrails of beds and floor mat type pressure sensors (Figure 1(b)) were put at bed side. Both sensors had been used for detecting the elderly falling down from his/her bed or trying to sneak out of the bed. However, those sensors had little effect on *preventing* accidents from occurring because: (1) the elderly, though suffering from senile dementia, often learn how to escape being detected by the sensors, (2) the sensors often emit false alarms when, for example, a person turns over and touches the sensor by chance while sleeping, and (3) the sensors detect the occurrence of accidents but cannot prevent accidents from occurring even if they work correctly.



(a) Tiny type (1×1×2cm; comparison with an US cent coin) (b) Long life battery type (Active for 2mon. with Li-Ion battery)

Figure 2: Variety of Ultra Badges

According to the caregivers, more than 85% of the residents are suffering from senile dementia so they cannot expect the residents to put on any devices. Therefore, we have to monitor the elderly without putting any devices on their bodies. And, moreover, cameras are unacceptable because they may invade the privacy of the elderly.

3.2 The Ultra Badge System

The authors have been developing an ultrasonic 3D tag system(Nishida et al., 2004; Hori et al., 2003) which tracks positions of multiple ultrasonic tags continuously for monitoring human behaviors. We call it *Ultra Badge System*.

The Ultra Badge System consists of ultrasonic receivers embedded in the environment and wireless small ultrasonic emitters. We named the emitter *Ultra Badge*. Figure 2 shows two types of Ultra Badges developed by the authors. The left picture is a tiny type whose size is 1cm×1cm×2cm, and the right one is a long life battery type which uses a Li-Ion battery of mobile phone and is active for two months using sleep mode.

By embedding many receivers whose 3D positions are known beforehand in an environment, the system can obtain a badge's position from distance data using multi-lateration technique. Experiments conducted in our laboratory exhibited that the accuracy of position estimation was about 20 to 80mm and the resolution was about 15mm in horizontal directions and about 5mm in vertical direction by using a robust estimator, RANSAC(Fischler and Bolles, 1981).

3.3 Outline of the Ultrasonic Sensor System for Detecting Falls in a Nursing Home

From the interview with caregivers, we summarized the targets of our sensor system as follows:

- The system prevents falls from occurring in the nursing home,

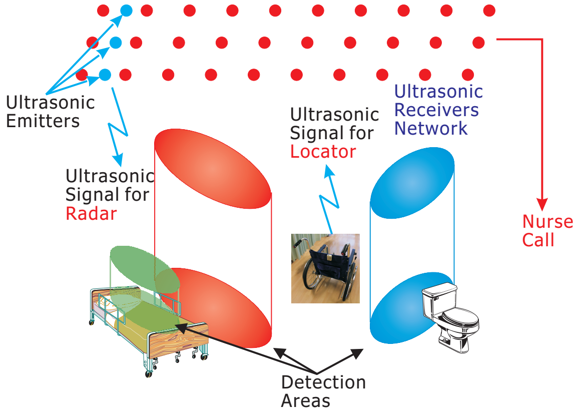


Figure 3: Schematic diagram of the Ultrasonic Sensor Network System for a nursing home

- The system monitors beds, bedsides and the side of toilet seats because the locations where falls occur are relatively limited to those places,
- The system monitors the elderly remotely and does not expect them to put any devices on their bodies,
- The system expects the elderly to use wheelchairs or walkers,
- The system uses an existing nurse call system to send alarms to caregivers when it detects accident-prone activities, and
- The system must respect and must not invade the privacy of the elderly.

We designed an *Ultrasonic Sensor Network System for the Nursing Home* based on the above considerations. Figure 3 is a schematic diagram of the system. The system consists of (1) embedded ultrasonic receivers, (2) embedded/wireless ultrasonic emitters (Ultra Badges) and (3) a sensor network which connects receivers and emitters. In addition to these main components, the system uses a synchronous signal generator to synchronize the emitters/receivers internal timers, an RF transmitter to activate wireless emitters, and a PC for data processing.

The system is composed of two subsystems: *wheelchair locator* and *ultrasonic radar*. The wheelchair locator subsystem uses Ultra Badges attached to wheelchairs to monitor their position remotely and the ultrasonic radar subsystem uses ultrasonic emitters embedded in the ceiling to monitor activities of the elderly on their beds. The subsystems are connected to a nurse call system and they call caregivers whenever they detect predefined events leading to accidents. Details of these subsystems are described in Section 4.

In this system, information transmitted through the air is wireless emitters' IDs only, and ultrasonic pulses sent from any emitters do not carry any information on the individuals being monitored. The sys-

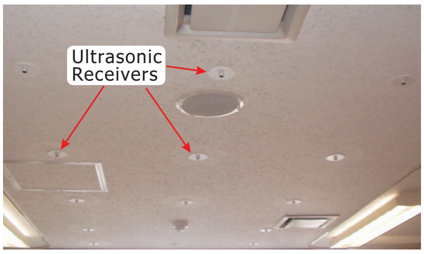


Figure 4: Ultrasonic receivers on the ceiling

Figure 5: Enlarged view of a receiver

Figure 6: A wheelchair and an Ultra Badge attached

tem does not collect unnecessarily rich information, such as the images taken by cameras. We can therefore conclude that the level of privacy invasion is minimized in this ultrasonic sensor network system.

4 IMPLEMENTATIONS OF THE SYSTEM AND EXPERIMENTAL RESULTS

This section presents a wheelchair locator subsystem and an ultrasonic radar subsystem in detail. The aim of the former subsystem is to detect the wheelchair approaching one of areas where falls are likely to occur and the aim of the latter is to detect the elderly getting up and going out of their beds.

4.1 Wheelchair Locator Subsystem

The authors installed the Ultra Badge System for monitoring positions of a wheelchair in one room of the nursing home. We embedded 99 ultrasonic receivers on the ceiling of the room. Appearance of the ceiling and an enlarged view of a receiver are shown in Figure 4 and 5, respectively. All the other apparatus are hidden behind the ceiling so the room looks the same as the other rooms except for the ceiling.

An Ultra Badge was attached to the wheelchair that the subject of this experiment uses. Figure 6 shows the wheelchair and an Ultra Badge attached to the back of the seat. The system activates the badge at 5 Hz and tracks its position continuously.

In the room, we defined *detection area*s in front of the bed that the subject uses and at the entrance of a toilet. The subsystem is connected to a nurse call system and, when it detects the wheelchair entering one of the areas, it notifies caregivers that the subject is approaching the place where accident is likely to occur. Though we have not measured the time from the nurse call alarm to caregivers' arrival, it seems that

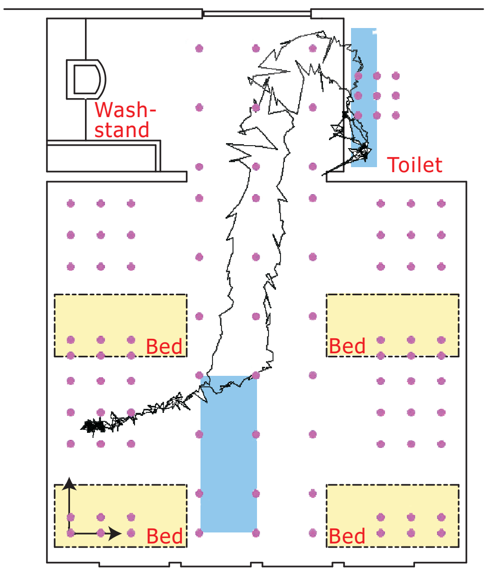


Figure 7: Trajectory of the wheelchair

both the position of detection areas and the timing of alarm work for caregivers to support the subject.

4.2 Experimental Results of the Wheelchair Locator Subsystem

This subsystem has been running since January, 2004, and taking logs of wheelchair's position. Figure 7 is its trajectory obtained during the operation. The line segments are the trajectory and purple dots are the receivers' positions on the ceiling. Yellow and blue rectangles indicate bed positions and detection areas, respectively. The subject uses the lower-left bed so we preset the detection areas in front of the bed and at the entrance of the toilet.

This experimental data was obtained from 8:00AM to 10:00AM on Aug. 15th, 2004 and, according to the log, the system correctly sent alarms when the wheelchair got into either detection area. So we may say that the system was almost working fine.

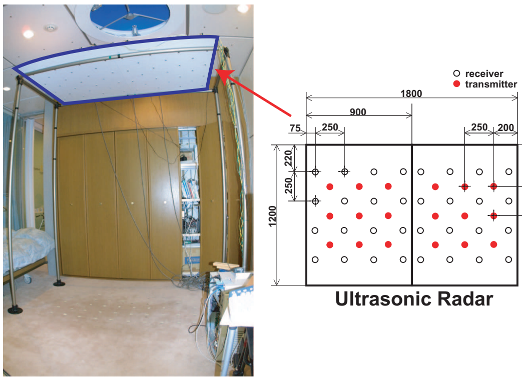


Figure 8: Ultrasonic emitters/receivers on the ceiling

During the operation, the system detected the other events that even caregivers did not know at all. One of such events that the system disclosed was the following:

> In one night, the system sent alarms several times so a caregiver went to the nursing room to find that the subject was going to the toilet with her wheelchair.

The contact-type sensors used for the subject could not have detected such events at all so no caregivers had thought the subject went out of bed in the night. But, with the assistance of this system, they found that the subject had symptoms of frequent urination.

Such sneaking out could not be detected with a wearable-type device if the subject (deliberately) forgot to put the device on. Cameras could have detected the events if their installation was permitted in the nursing room, but they need someone to keep watching *all* monitors to detect such events. So we are confident that this is a good example which exhibits the effectiveness and the superiority of our system.

4.3 Ultrasonic Radar Subsystem

The wheelchair locator subsystem is a system to locate wheelchair so, theoretically, it cannot detect the activity of the elderly on their beds. But, of course, falls from bed must also be avoided and we need to monitor the activity on beds to detect such accidents. So we developed this ultrasonic radar subsystem.

The subsystem comprises several ultrasonic emitters and receivers embedded on a ceiling. The subsystem activates emitters one by one and measures time-of-flight of ultrasonic pulses, just the same as the wheelchair locator subsystem. When the system obtains the distance data, the reflection point is located on a spheroid whose foci are the emitter and the receiver. So the position of the reflection point is calculated by solving simultaneous equations of at least three spheroids.

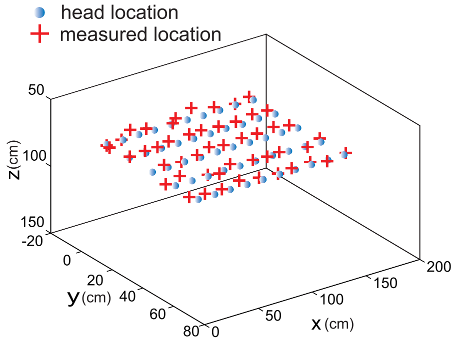


Figure 9: Evaluation of localization accuracy of human head

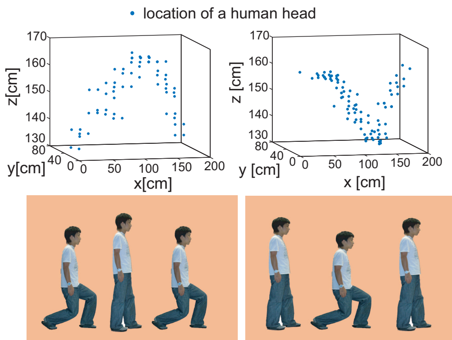


Figure 10: Tracking a head of moving human

Figure 8 depicts our experimental setup. In this setup, we set 18 ultrasonic emitters and 32 receivers on a panel, and placed it as a ceiling at 230 cm height from the floor level. In this experimental system, the sampling frequency is 1 Hz, i.e. every emitter is activated every one second in turn.

This subsystem is still under development and is not installed in the nursing home. So the experimental results presented in the next subsection were obtained by this experimental setup.

4.4 Experimental Results of the Ultrasonic Radar Subsystem

The accuracy of localization was measured to evaluate the ability to detect the human head location. Figure 9 shows the results, where the blue dots and the red crosses indicate true positions of the head and positions measured by the subsystem, respectively. All the distance errors between corresponding points were within 5 cm so we think that the system has sufficient accuracy to locate human head.

As the subsystem calculates the reflection point periodically, it can obtain a trajectory of a human head, though the resolution is not so precise because of the sampling rate. Figure 10 illustrates the tracking results. The upper parts show the trajectories when the subject moved as shown in the lower parts.

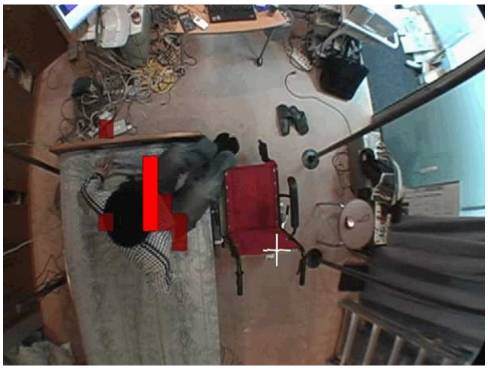


Figure 11: Coordination of the wheelchair locator subsystem and the ultrasonic radar subsystem

4.5 Integration of Two Subsystems

When these two subsystems work cooperatively, they can monitor the activities of the elderly on beds and in the room. We integrated them into an experimental system shown in Figure 11. The figure illustrates an example of cooperation of two subsystems. In the figure, a person is sitting on a bed and transferring to a wheelchair. The red rectangle indicates the position of his head and the white cross indicates the position of the Ultra Badge attached to the wheelchair.

One of the advantage of this integration is that both subsystems use the same ultrasonic technology; that is, installing a large-scale ultrasonic sensor network system suffices both subsystems' requirements. The total system is expected to work for detecting accident-prone activities and for preventing accidents from occurring in a nursing home.

5 CONCLUSIONS

This paper presented an ultrasonic sensor network system for nursing homes. We developed two subsystems. The wheelchair locator subsystem was installed in a nursing home and has been running successfully. The ultrasonic radar subsystem is still under development but will be installed in the nursing home soon as its experimental results satisfied our requirements.

The authors think that accidents on the elderly will be avoided or minimized when both subsystems work cooperatively; i.e., the total system monitors the elderly, recognizes accident-prone activities and notifies their occurrence to caregivers beforehand. If this sensor network system works in place of caregivers, their workloads are alleviated and they will be able to spare their time for high touch care for the elderly.

The authors believe that nursing homes will be fully *sensorized* in the near future.

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